Municipal Solid-State
STREET LIGHTING
CONSORTIUM

SSL Not As Simple As It Seems: Things To Know and Things To Consider

September 30, 2010

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- Agenda
  - LM79 & LM80 What They Are and What They Are Not
  - “Blue” Light
  - Photopic/Scotopic/Mesopic IES Position
  - LED and Luminaire Lifetime
  - Warranties
  - Lumens Per Watt Metric

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LM-79 & LM-80
What They Are and What They Are Not

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847-390-5241

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Agenda

- LM-79: What it is and what it is not
- LM-80: What it is and what it is not
- LM79 & LM80 Report Examples
- Next Steps

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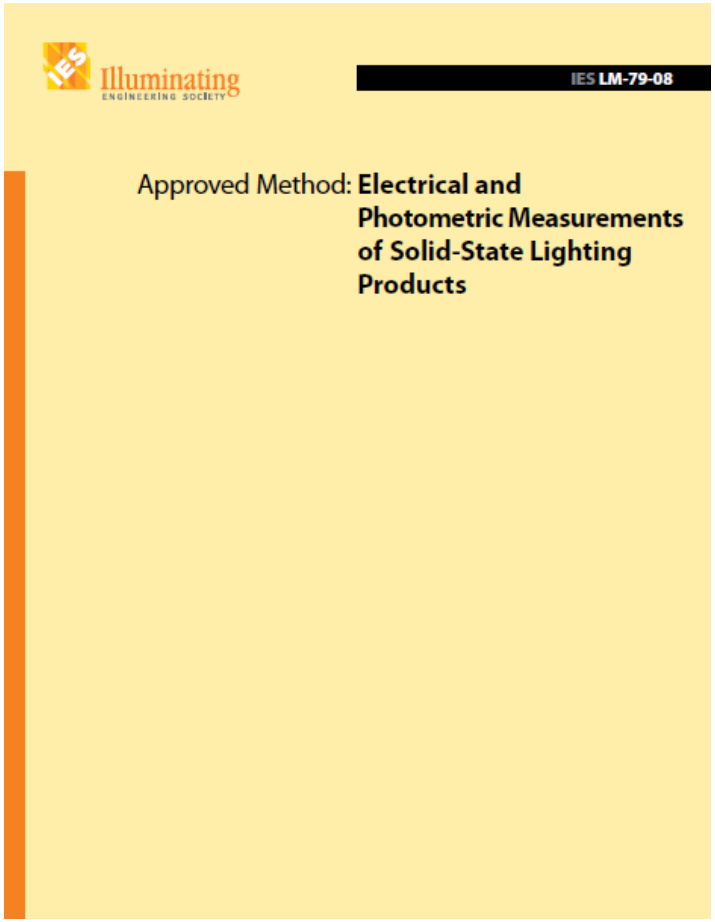
LM-79 Overview

- **LM-79 is a IES testing procedure for the Electrical and Photometric Measurements of Solid State Lighting**
- **As a member of the IES Board of Directors, I was part of the overall approval process**

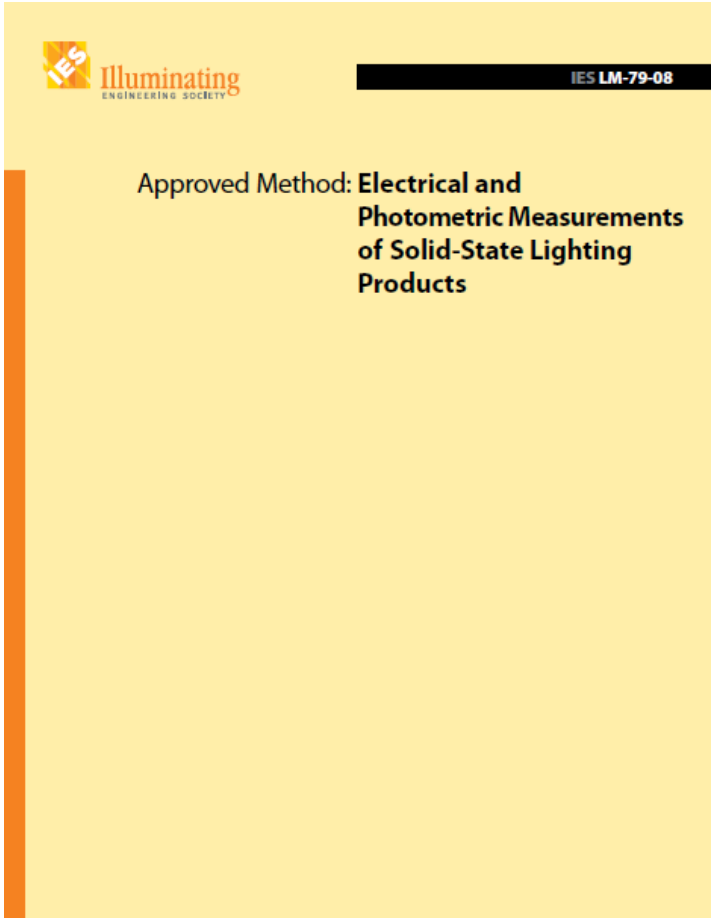
LM-79 Scope

- **LM-79 establishes testing methodology;**
  - **25C Ambient**
  - **Power Supply**
  - **Stabilization**
  - **Orientation**
  - **Electrical Instruments**
  - **Testing Equipment**



LM-79

- **LM-79 defines what information is required;**
  - **Total Light Output**
  - **Voltage, Current, Power**
    - **Calculates Efficacy**
  - **Lumen Distribution**
  - **CCT, CRI**
  - **Spectral Distribution**
  - **Testing lab and equipment used**



LM-79

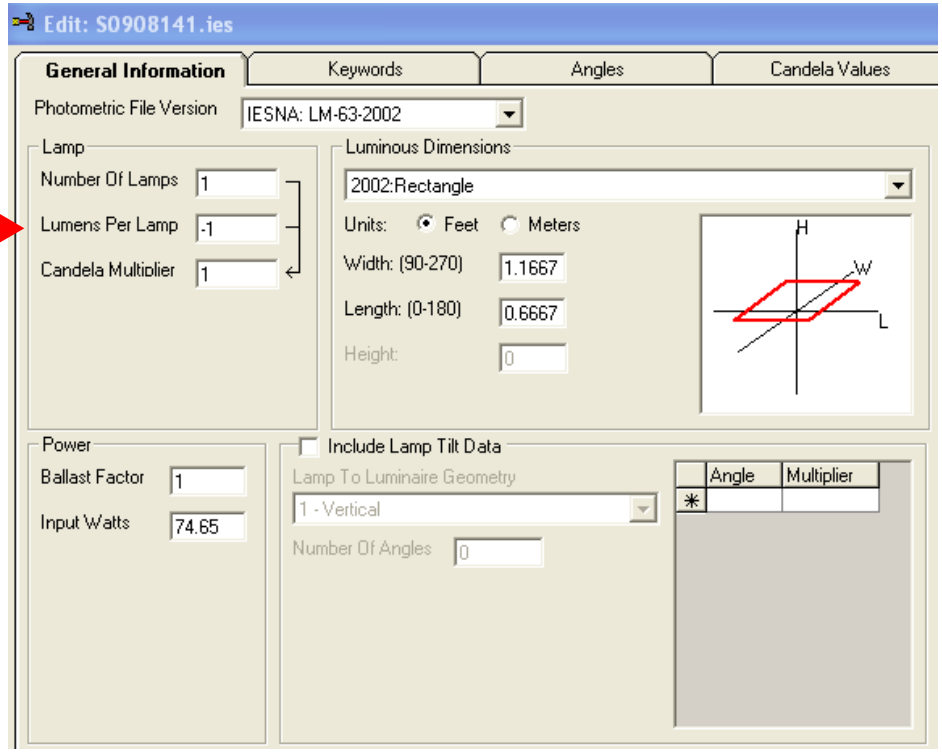
- **LM-79 requires that solid state lighting products be tested to "Absolute Photometry"**
- **Conventional HID/Fluorescent uses "Relative Photometry"**
  - **Lamp & Luminaire are tested independent of each other**
  - **Design programs AGI/Visual allows you to "Prorate" luminaire output based on the lamp rating**
  - **LED products cannot be done this way**
  - **If manufacturers state you can "Prorate" their LED products, they are NOT following LM-79**

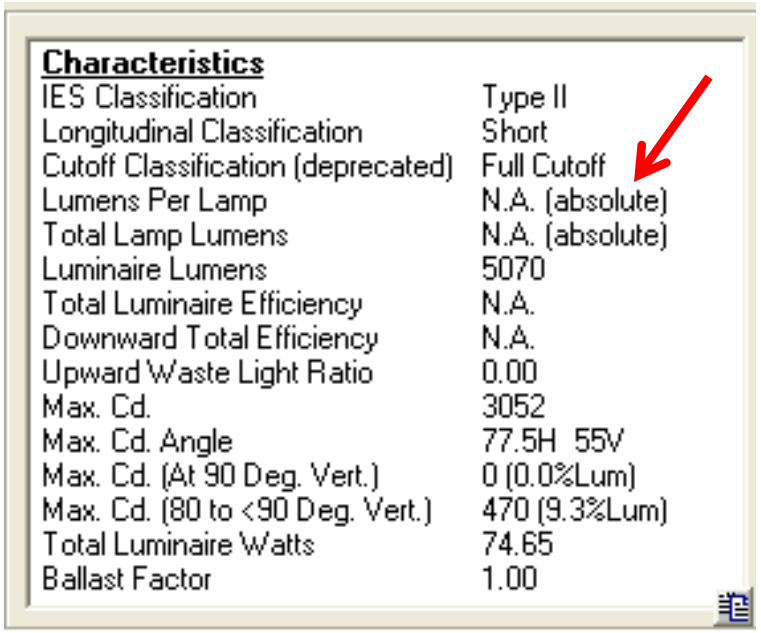
LM-79

- **Absolute Photometry**
  - **Lumen output of LED based luminaires are dependent on the Chip, Thermal Management, Drive Current, Optical System**
  - **LED based luminaires and lamps must be tested as a complete unit/system**
- **Only DOE recognized Caliper testing laboratories results should be utilized**

LM-79

- **Absolute Photometry – How To Identify**





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LM-79 DOE Recognized Labs

Laboratories Performing Integrating Sphere Testing for CALiPER

- Independent Testing Laboratories Inc. – Boulder, CO
- Intertek - Cortland, NY
- Luminaire Testing Laboratory Inc. – Allentown, PA
- Lighting Sciences Inc. – Scottsdale, AZ
- OnSpeX/CSA International – Atlanta, GA
- Aurora International Testing Laboratory (PDF 3.0 MB) – Aurora, OH
- Orb Optronix Inc. – Kirkland, WA

Laboratories Performing Goniophotometry Testing for CALiPER

- Independent Testing Laboratories Inc. – Boulder, CO
- Intertek – Cortland, NY
- Luminaire Testing Laboratory Inc. – Allentown, PA
- Lighting Sciences Inc. – Scottsdale, AZ
- OnSpeX/CSA International – Atlanta, GA

Laboratories Qualified by CALiPER to Perform Integrating Sphere Testing

- GE Consumer & Industrial – Lighting Product Testing Laboratory (PDF 35 KB) – Cleveland, OH
- OSRAM Sylvania Metrology & Analytic Services (PDF 59 KB) – Beverly, MA

Laboratories Qualified by CALiPER to Perform Goniophotometry Testing

- GE Consumer & Industrial – Lighting Product Testing Laboratory (PDF 35 KB) – Cleveland, OH
- OSRAM Sylvania Metrology & Analytic Services (PDF 59 KB) – Beverly, MA

- Ecos – Portland, OR
- Gamma Scientific – San Diego, CA – Troy, NY
- Lighting Research Center; Rensselaer Polytechnic Institute – Troy, NY

LM-79 Recap

- LED luminaire and lamp photometry is different than conventional technologies
- Provides the tools to perform this testing
- Absolute photometric reports and IES files should be available for each luminaire
- Use of prorating luminaire photometrics is not an accepted procedure. This results in increased testing costs.
- Manufacturers are required to provide independent testing lab reports
  - Testing lab should be Caliper approved
- Efficacy ratings should be verified by independent reports
- Be cautious of claims that cannot be supported with data

LM-79 Sample Reports

itl boulder
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

Page 1 of 3

REPORT NUMBER: ITL63826
DATE: 12/14/09
PREPARED FOR: BETA LIGHTING, INC.

CATALOG NUMBER: BXSL0212C-U (525mA)

LUMINAIRE: CAST GRAY PAINTED METAL HOUSING WITH CAST GRAY PAINTED METAL ACCESS DOOR, EXTRUDED FINNED METAL HEAT SINK, CAST GRAY PAINTED METAL FORWARD HOUSING PIECE, SIX CIRCUIT BOARDS EACH WITH 20 LEDS AND CAST GRAY PAINTED METAL TRIM PLATE, ONE CLEAR PLASTIC NON-INTEGRAL LENS BELOW EACH LED.

LAMPS: ONE HUNDRED TWENTY WHITE LIGHT EMITTING DIODES (LEDS), VERTICAL BASE-UP POSITION.

LED DRIVERS: TWO BETA LED CE366X01R0

NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT VOLTAGE (240VAC, 60Hz) TO THE LED DRIVER. CLIENT STATES LEDS HAVE BEEN SEASONED FOR A MINIMUM OF 100 HOURS.

INSTRUMENTATION: Kikusui PCR500L AC Power Source
Yokogawa WT210 Digital Power Meter
Optronics OL770 Spectroradiometer
ITL 1.5 Meter Diameter 4π Steradian Integrating Sphere

OBJECT OF TEST: Report the Absolute Flux in Lumens*, measure the Spectral Power Distribution, Correlated Color Temperature (CCT), Color Rendering Index (CRI), Chromaticity Coordinates (x,y), ANSI C78.377 Duv, and input electrical parameters to the luminaire.

PROCEDURE: The luminaire was provided by customer and the LEDs had an unknown number of burn hours. The luminaire was mounted inside the integrating sphere with the luminaire horizontal (LEDs facing down). The luminaire was allowed to stabilize at 240 VAC input. After stabilization occurred, spectral power distribution, CCT, CRI, x/y chromaticity coordinates, ANSI C78.377 Duv, and input electrical data were measured with the luminaire operating in the integrating sphere. In order to measure the mean performance, twenty data sets were recorded and averaged within the OL770. Readings were taken with the luminaire operating at 240 VAC input in a 25 +/-1 degree Celsius free air ambient and in accordance with IESNA LM-79-08. All data are traceable to the National Institute of Standards and Technology.

*NOTE: The total lumen output shown on this report was obtained from photometric test ITL63823.

RESULTS: (continued next page)

Checked:
Approved:

PHOTOMETRIC	
Total Integrated Flux (lumens)	13905*
SPECTRORADIOMETRIC	
Observer	CIE 1931 2 degree
Chromaticity Ordinate x	0.3211
Chromaticity Ordinate y	0.3429
Correlated Color Temp CCT (K)	6012
Color Rendering Index (CRI)	73
ANSI C78.377-2008 Duv	0.006
ELECTRICAL	
Input Voltage (Volts AC)	240.0
Input Current (mA AC)	936
Input Power (Watts)	220.2
EFFICACY (Lumens/Watt)	63.1

LM-79 Establishes What To Publish,
Not How To Publish,
Each Lab Produces Their Own Format

LM-79 Sample Reports

Les Industries Spectralux Inc.
Spectralux Industries Inc.

2750 Sabourin, Saint-Laurent (Quebec) H4S 1M2 Canada
Tel.: (514) 332-0082 Fax: (514) 332-3590 www.spectralux.ca

Photogoniometer Photometric Test Report

Standard(s): IESNA LM-31-95, IES LM-79-08

General Information		SSL Details		Driver Details	
Test Report	S0908141-R1	Description	65W White SSL	Type	Commercial
Test Date	14 August 2009	Lamp Lumens	-1	Description	75W
Report Date	14 August 2009	Serial Number	LXML-PWN3-0100	Manufacturer	HIGH PERFECTION TECH
Customer	LUMEC	Standard Designation	N/A	Catalog No.	LP1090-24-GG-170
Ambient	26.6 °C	Test Position	Horizontal	Voltage	120.00 V
Humidity	58.2 %	Comments	49LED-GPLS-LE2	Power Factor	0.9800

Luminaire Data

General Information		Optics		Aperture (feet)	
Manufacturer	LUMEC	Reflector	49 Clear LED Collimators	X	1.1667
Name	GPLS	Housing	Die Cast Aluminum	Y	0.6667
Catalog No.	GPLS-65W49LED4K-LE2	Lens	None	Z	0.0000

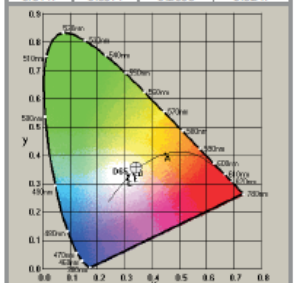
Remarks: SKT Position - Luminous Plan Opening Parallel to Horizon, Lamp Stabilization Time =120 mintes , Tota Operating Time = 240 minutes

LTL LUMINAIRE TESTING LABORATORY, INC.

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

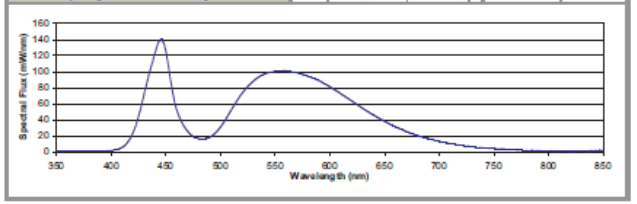
LTL Number: 17392 Date: 11-25-2009
Prepared For: Lighting Science Group Corp
Catalog Number: LSR2 CW R3 2B GR PCR
Luminaire: Cast aluminum housing, clear plastic enclosures.
Lamps: 48 White LEDs
LED Power Supply: One Mean Well CLG-150-36A
Luminaire Efficacy: 78.0 Lumens/Watt

Luminaire Input Voltage	Input Current	Luminaire Watts	Power Factor
120.0VAC	0.6392A	75.48W	0.984
Radiant Flux mW	**Luminous Flux lumen**	**Corr. Color Temperature K**	**Color Rend. Index Ra**
18000.76	5885.830	5145	68.9
Chroma x	**Chroma y**	**Chroma u**	**Chroma v**
0.3417	0.3577	0.2068	0.3247



Chromaticity Diagram CIE 1931, 2 degree

Wavelength in nm	Spectral Flux in mW/nm	Wavelength in nm	Spectral Flux in mW/nm
350	0.3174	610	72.4580
360	0.7201	620	63.4990
370	0.6395	630	54.2760
380	0.9005	640	45.6860
390	0.9917	650	38.0700
400	1.6808	660	31.1530
410	5.4909	670	25.2600
420	23.9240	680	20.2830
430	70.9300	690	16.3330
440	122.6800	700	12.9260
450	125.8500	710	10.2340
460	52.3110	720	8.1639
470	25.4860	730	6.3204
480	16.4330	740	4.9019
490	18.0690	750	3.9047
500	30.9740	760	3.2325
510	52.6610	770	2.5281
520	73.6060	780	1.8186
530	88.2290	790	1.5311
540	96.9410	800	1.1479
550	100.1500	810	0.6533
560	101.1700	820	0.4220
570	98.6160	830	1.0455
580	94.2020	840	0.9412
590	88.9080	850	1.5715
600	81.1280		



TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.

THE LABORATORY THAT CONDUCTED THE DETAILED TESTING IN THIS REPORT HAS BEEN QUALIFIED, VERIFIED, AND RECOGNIZED FOR LM-79 TESTING FOR ENERGY STAR FOR SSL BY THE DOE'S CALIPER PROGRAM.

Approved By:

Municipal Solid-State
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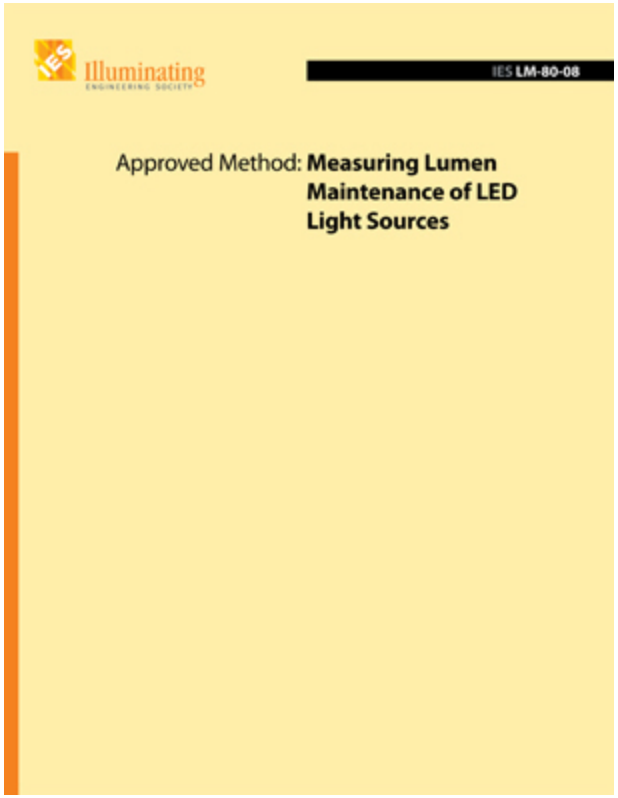
LM-80 Overview

- **LM-80 is a IES testing procedure for Measuring Lumen Maintenance of LED Light Sources**
- **As a member of the IES Board of Directors, I was part of the overall approval process**

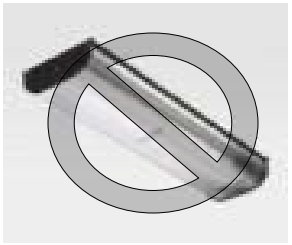
LM-80 Definition

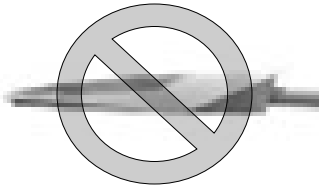
- **LM- 80 covers the measurement of lumen maintenance of LED packages, arrays and modules**

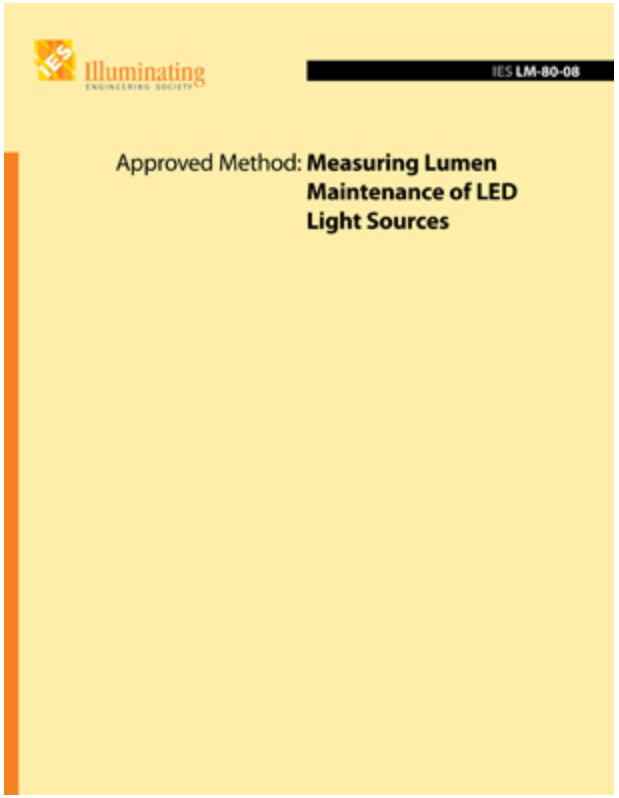


LM-80

- **LM- 80 does NOT cover LED luminaires or lamps**







LM-80 – Lumen Maintenance

- LED luminaires and lamps do not “fail” like conventional sources
- Conventional lamps burn out
  - Conventional lamp life is rated when 50% of the lamps in a installation burn out
- LED luminaires and lamps gradually decrease in output over time
- IES has determined end of life of LED products to be when the lumen output is 70% of its initial (30% depreciation)
  - This is known as L70
- Total life is known as L70B50
  - L70B50 is the amount of time for the light output of 50% of a set of LEDs to fall to 70% of their original light output under a given set of operating conditions.

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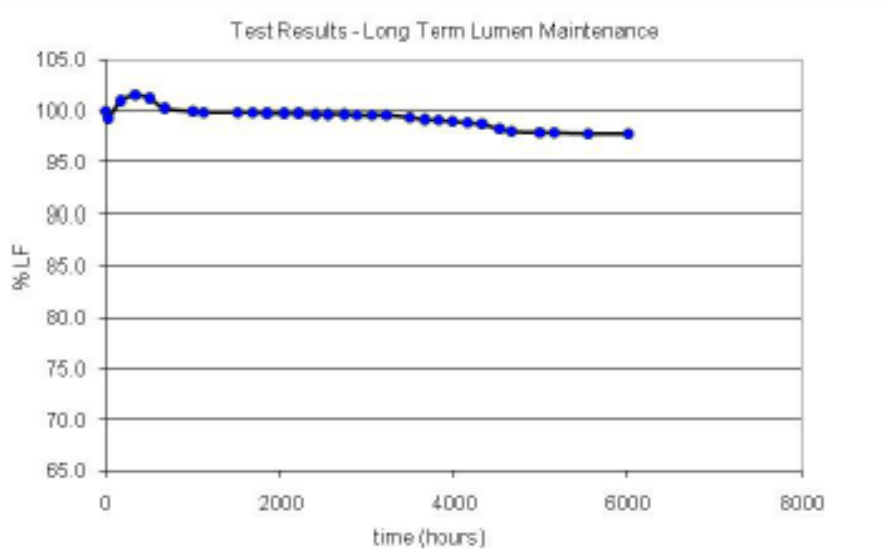
LM-80 – LED Lifetime

- The DOE has suggested that useful life of LEDs to be 35,000 to 50,000 hours
- Claims beyond these values cannot currently be substantiated using available approved methods, or historical data to support claims beyond these levels
  - 1 year = 8,736 hours
  - 50,000 hours = 5.7 years
  - 150,000 hours = 17.2 years
- DOE document “Lifetime of White LEDs”

Light Source	Range of Typical Rated Life (hours)* (varies by specific lamp type)	Estimated Useful Life (L_{70})
Incandescent	750-2,000	
Halogen incandescent	3,000-4,000	
Compact fluorescent (CFL)	8,000-10,000	
Metal halide	7,500-20,000	
Linear fluorescent	20,000-30,000	
High-Power White LED		35,000-50,000**

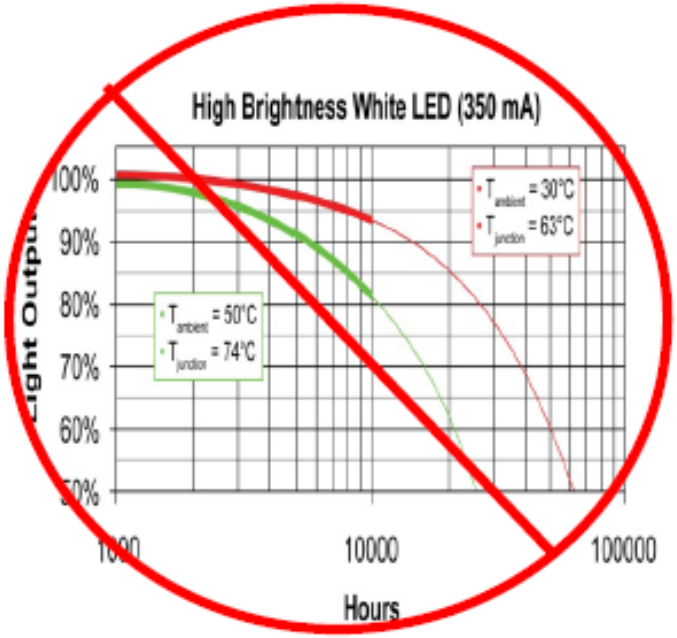
LM-80

- **LM-80 however does NOT provide testing procedures for a complete luminaire**
- **LM-80 just provides the tools to measure the lumen maintenance of a LED package, array or module at 6,000 hours**



LM-80

- **LM-80 does NOT provide guidance for estimating or extrapolating lumen maintenance beyond 6,000 hours**
- **LM-80 does NOT provide guidance for estimating luminaire or lamp life based on this data**



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Future Standards in Development – TM21

- To address long term performance of LED products IES is currently developing a supplemental document to LM-80 called TM-21
- TM-21 will utilize LM-80 data
- TM-21 will provide theoretical models to use in predicting lumen maintenance at the luminaire or lamp level
- This document is still 3-6 months away from adoption

LM-80 Recap

- **DOE recommends the following**
  - **Use high quality, high output LEDs**
  - **LED reports should be based on LM-80 test procedures**
  - **LED luminaire manufacturers should provide temperature data for LEDs when operated in a luminaire**
  - **Be cautious of claims that cannot be supported**
  - **LM-80 is only the first part of the metric, the industry does not have the rest of the parts to determine the life of a luminaire**

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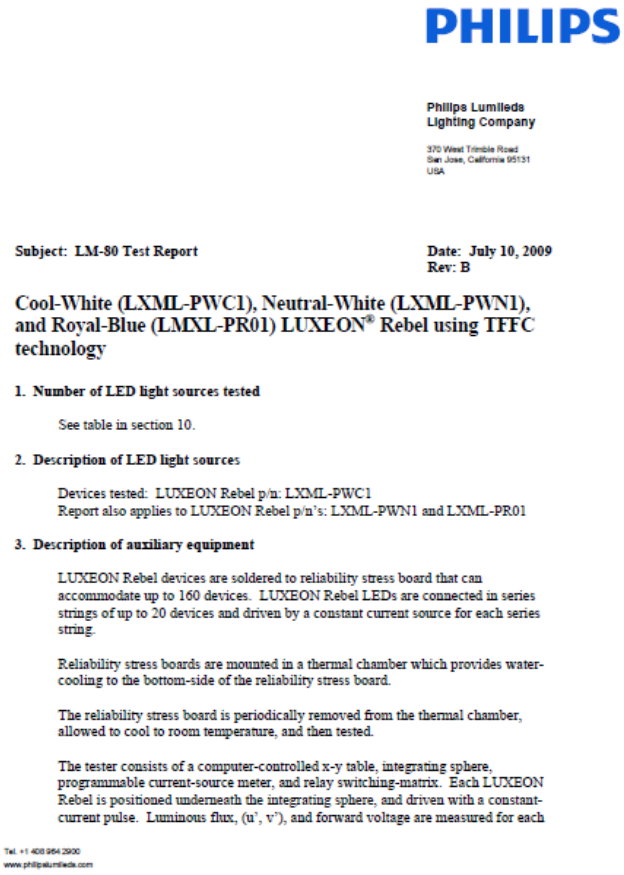
LM-80 Sample Report



PHILIPS

Philips Lumileds
Lighting Company

370 West Trimble Road
San Jose, California 95131
USA

Subject: LM-80 Test Report **Date: July 10, 2009**
Rev: B

Cool-White (LXML-PWC1), Neutral-White (LXML-PWN1), and Royal-Blue (LMXL-PR01) LUXEON® Rebel using TFFC technology

1. Number of LED light sources tested

See table in section 10.

2. Description of LED light sources

Devices tested: LUXEON Rebel p/n: LXML-PWC1
Report also applies to LUXEON Rebel p/n's: LXML-PWN1 and LXML-PR01

3. Description of auxiliary equipment

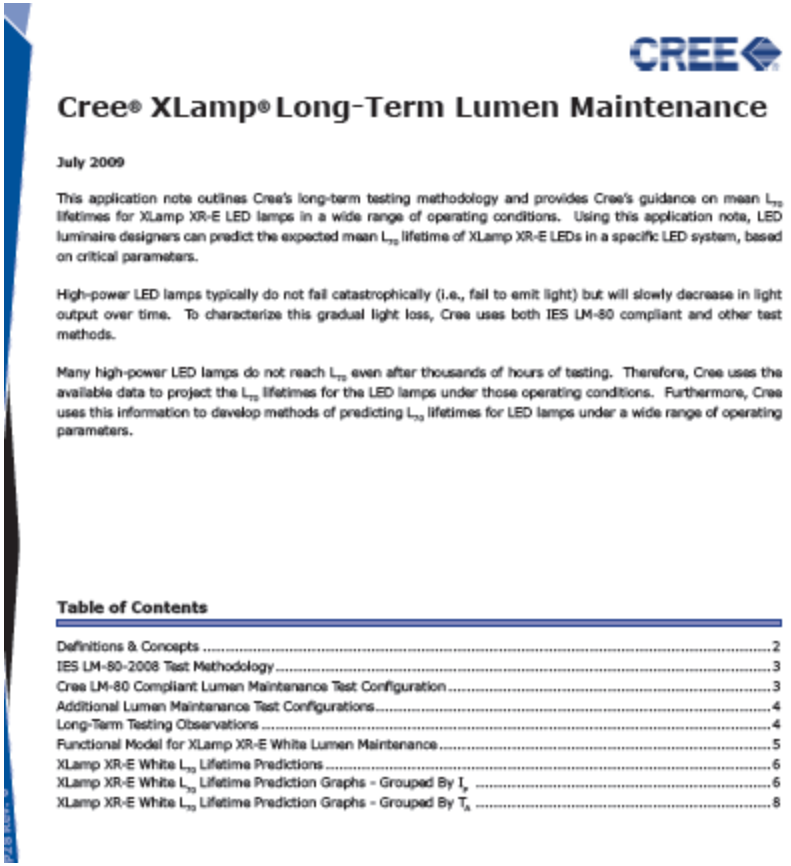
LUXEON Rebel devices are soldered to reliability stress board that can accommodate up to 160 devices. LUXEON Rebel LEDs are connected in series strings of up to 20 devices and driven by a constant current source for each series string.

Reliability stress boards are mounted in a thermal chamber which provides water-cooling to the bottom-side of the reliability stress board.

The reliability stress board is periodically removed from the thermal chamber, allowed to cool to room temperature, and then tested.

The tester consists of a computer-controlled x-y table, integrating sphere, programmable current-source meter, and relay switching-matrix. Each LUXEON Rebel is positioned underneath the integrating sphere, and driven with a constant-current pulse. Luminous flux, (u', v'), and forward voltage are measured for each

Tel. +1 408 964 2900
www.philipslumileds.com



CREE

Cree® XLamp® Long-Term Lumen Maintenance

July 2009

This application note outlines Cree's long-term testing methodology and provides Cree's guidance on mean L_{70} lifetimes for XLamp XR-E LED lamps in a wide range of operating conditions. Using this application note, LED luminaire designers can predict the expected mean L_{70} lifetime of XLamp XR-E LEDs in a specific LED system, based on critical parameters.

High-power LED lamps typically do not fail catastrophically (i.e., fail to emit light) but will slowly decrease in light output over time. To characterize this gradual light loss, Cree uses both IES LM-80 compliant and other test methods.

Many high-power LED lamps do not reach L_{70} even after thousands of hours of testing. Therefore, Cree uses the available data to project the L_{70} lifetimes for the LED lamps under those operating conditions. Furthermore, Cree uses this information to develop methods of predicting L_{70} lifetimes for LED lamps under a wide range of operating parameters.

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“Blue” Light & LED Lifetime

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September 30, 2010

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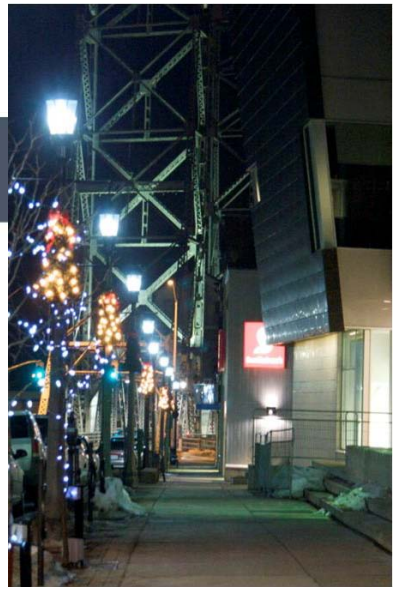


"Blue" Light Controversy

"…bluish light produces high levels of light pollution with significant environmental impact. Short wavelength light also increases sky glow disproportionately. In addition, blue light has a greater tendency to affect living organisms through disruption of their biological processes that rely upon natural cycles of daylight and darkness, such as the circadian rhythm. …Developers of light sources should be required to refine their products to limit blue light at wavelengths shorter than 500 nm."

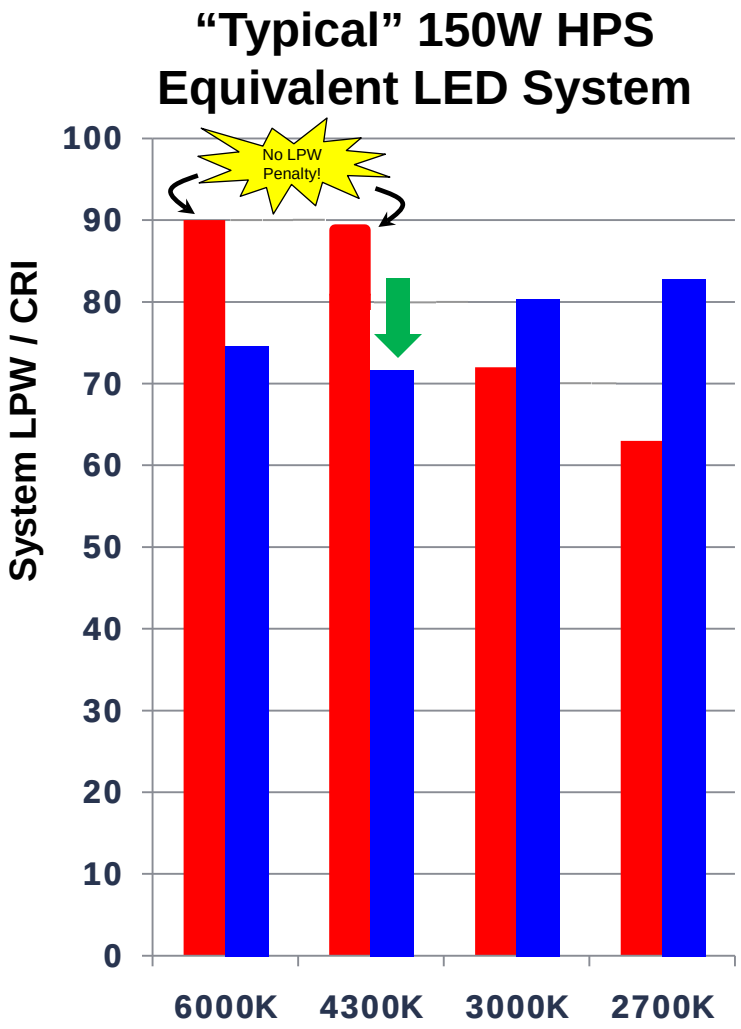
- IDA 10/7/2009

"…IDA's recommendations of curtailing emissions of light wavelengths shorter than 500 nanometers over the complete life of the lamp and minimizing the use of light sources with a CCT above 3000 Kelvin are unsubstantiated, and are contrary to the Department of Energy's mission to improve energy efficiency and environmental quality. High CCT lighting for outdoor applications should be neither mandated nor prohibited at a national level; qualified designers should be free to determine the relative importance of color and efficacy for any given project."

- U.S. Department of Energy

Dream Come True For Dark Skies…?

CCT Impact on LED Efficacy



- LEDs can be produced in literally *ANY* CCT
- Nothing magic about 6000K
- 6000K became popular because it was the most efficient CCT; made the business case/payback look better
  - Fewer LEDs, fewer optics, smaller, lighter systems…
- New innovations have eliminated the trade-off of efficacy for CCT
  - LED street lighting now has a high-efficacy option at 4300K: so-called "Outdoor White"
- The technical path to high-efficacy 3000K is not obvious

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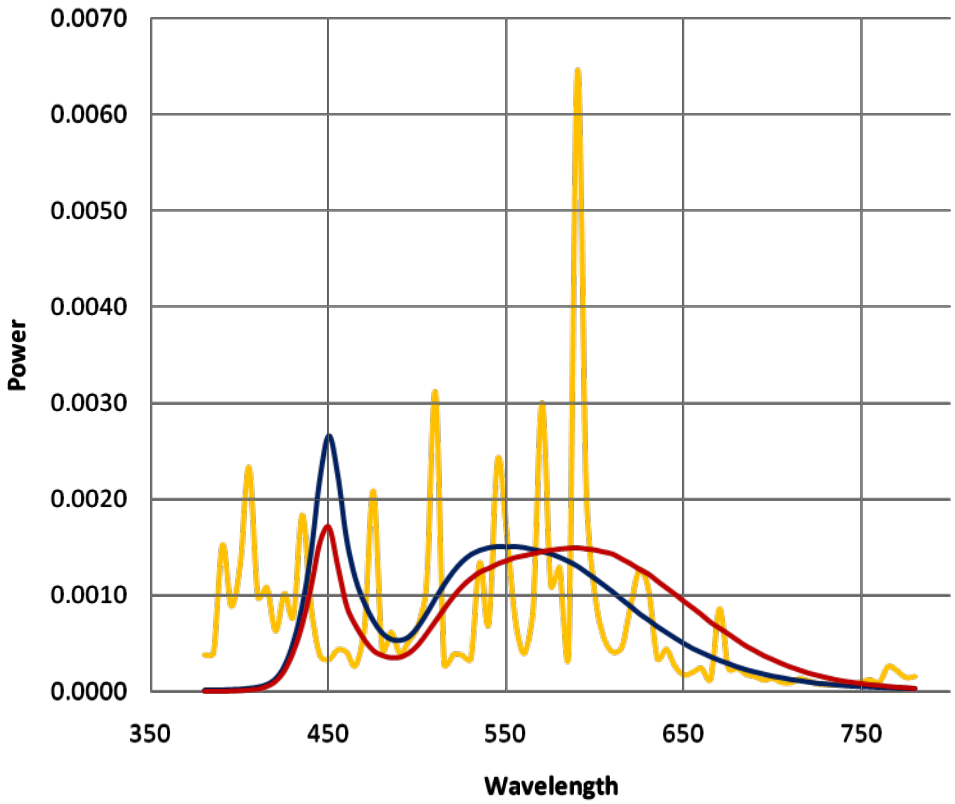
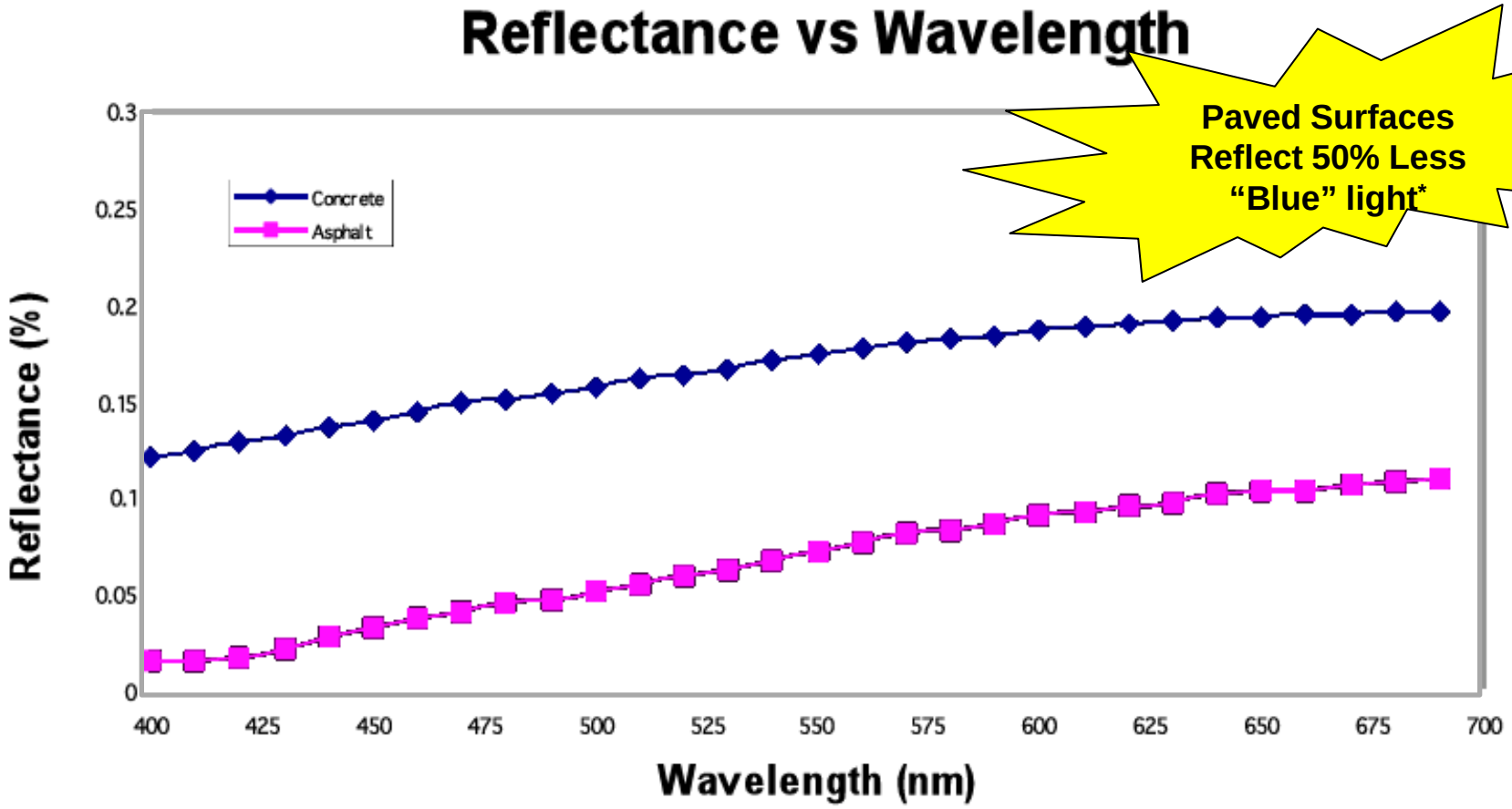
SPD Comparison at same Light level



Lamp Type	% Energy <500nm
Metal Halide	34%
Cool White LED	31%
Mercury Vapor	27%
T8 Fluorescent	22%
Outdoor White LED	20%

If "Blue" light were a health problem, we'd know if by now…

Reflectance vs Wavelength



Paved Surfaces Reflect 50% Less "Blue" light*

PCA Portland Cement Association

* A Sustainable Approach to Outdoor Lighting Utilizing Concrete Pavement, Portland Concrete Association, 2009

Photopic/Mesopic/Scotopic

Illuminating Engineering Society

IES Position Statement (PS-02-10)

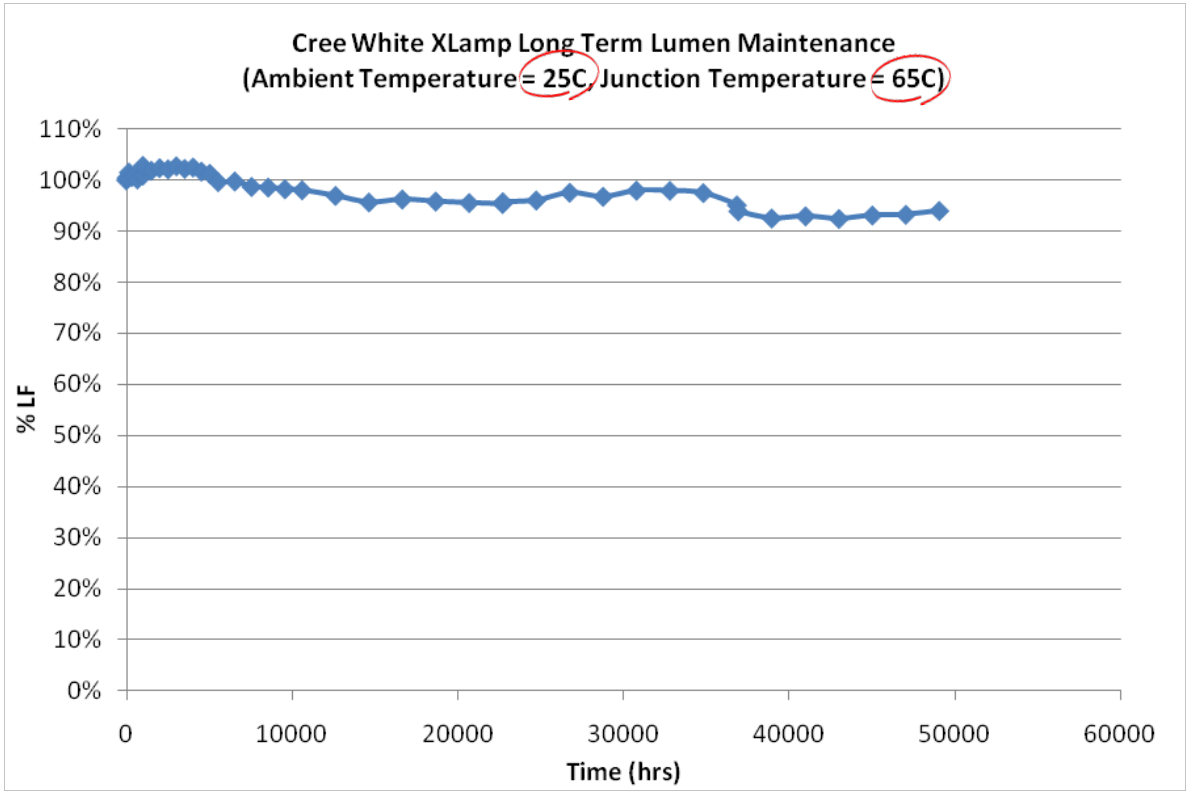
Use of Spectral Weighting Functions for Compliance with IES Recommendations

Research into the suitability of using weighting functions other than the photopic sensitivity function is ongoing. At present the research is not considered sufficient to support the application of any alternative to photopic visual sensitivity function.

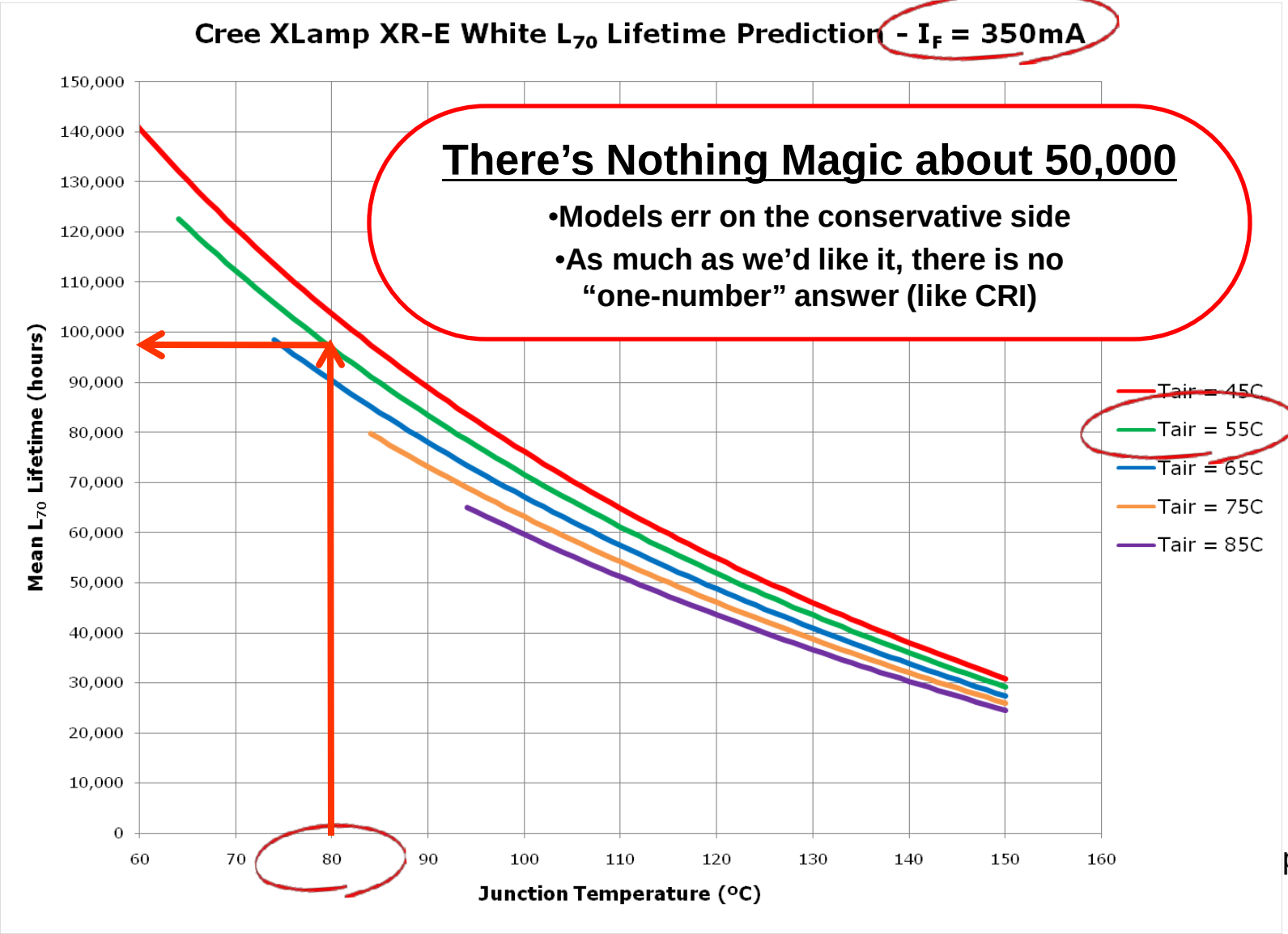
The IES recognizes the scotopic luminous efficiency function as a valid and recognized luminous efficiency function. However, the use of "scotopic lumens", "scotopic footcandles" or other similar "scotopic" metrics are not valid metrics to be compared to any IES published recommendation unless the publication specifies that the units are scotopic units. Unless specified otherwise, IES units are always based on the photopic luminous efficiency function and are thus photopic.

The IES maintains that the photopic illuminance levels prescribed in the ninth edition of the IES Lighting Handbook apply; that is, as long as the photopic illuminances used in practice are consistent with IES recommendations, the methods by which these are achieved are not specific to spectrum and the IES neither advocates nor precludes the use of spectrum in lighting calculations.

LEDs Last Forever!! [under ideal conditions]



Well-designed systems with Lighting-class LEDs at low T_A, T_J will run a very, very long time…


Cree XLamp XR-E White L_{70} Lifetime Prediction - I_F = 350mA
There's Nothing Magic about 50,000
•Models err on the conservative side
•As much as we'd like it, there is no "one-number" answer (like CRI)
Mean L_{70} Lifetime (hours)
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
60
70
80
90
100
110
120
130
140
150
160
Junction Temperature (°C)
Tair = 45C
Tair = 55C
Tair = 65C
Tair = 75C
Tair = 85C

LED Lifetime Is Irrelevant

System Lifetime is What Creates Value

Heat Sink: Linchpin of the entire system. If this is poorly designed, all the other components can be compromised

Driver: Currently the weakest point of the system, but the big companies are working on this

LED Lamps: Practically never fail; depreciate very slowly in a well-designed system

Optical Components: Can (rarely) yellow over time and lose light; system design choice

LED Luminaire Life

- L70 only provides lumen depreciation
- Many factors that can affect the speed of lumen depreciation and luminaire life
  - Temperature extremes
  - Humidity
  - Moisture incursion
  - Voltage and current fluctuations
  - Driver or other electrical component failure
  - Damage or degradation of the encapsulant material covering LEDs
  - Wire bounds

LED Luminaire Life

- Many factors that can affect the speed of lumen depreciation and luminaire life
  - Printed circuit boards
  - Mechanical components
  - Thermal systems
  - Housing
  - Gaskets and sealants
  - Color shift

- Refer to DOE documents:
  - “LED Luminaire Reliability”
  - “LED Luminaire Lifetime: Recommendations for Testing and Reporting

Warranties

- Warranties typically are for the luminaire, not lumen depreciation
- Per the DOE “LED Luminaire Lifetime Recommendations, May 2010”
  - The warranty may logically be shorter than the claimed lumen lifetime

- Use manufacturers who design and build the luminaires, that have the experience and knowledge

Luminaire Comparisons

- Lumens Per Watt – Can be a misleading metric
- Need to look at the entire photometric performance
  - Distribution: Short, Medium, Long
  - Coefficient of Utilization: Downward Streetside vs. Downward House Side - % Total Lamp Lumens
    - 57 L/W CU HS = 77%, 92 L/W CU HS = 62%
  - Light Trespass
  - BUG Rating
  - Required RP8 Light Levels
    - LEDs allows you to fine tune the design

Municipal Solid-State
STREET LIGHTING
CONSORTIUM

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